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RELATION BETWEEN HEAT SOURCE AND ELECTRODE FORCE OF DISSIMILAR METAL WELDING

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ABSTRACT

The focus of this study was on resistance spot welding (RSW) in combination between stainless steel and aluminum alloy. The relation between heat source and electrode force was figured out. To clarify that relation, a cross-section transformation with a variable electrode force and a fixed welding current was investigated. An expansion source was changed accordingly from aluminum alloy to stainless steel and a heat affected zone of stainless steel increased by increasing the electrode force, because the heat source was moved from an interface to the inside of stainless steel. As a result, no voids and intermetallic compounds existed in the aluminum alloy side and the thickness of the intermetallic compound layer at the interface was around 1.0-1.5 µm. Therefore, the tensile shear strength was increased and its variability was decreased.

KEYWORDS: Resistance Spot Welding, Dissimilar Metal Welding, Electrode Force, Heat Source, Tensile Shear Strength

INTRODUCTION

Recently, transportations such as automobiles have become indispensable in our lives. A great amount of energy is required to operate these machines. Weight reduction is one method to improve the fuel efficiency of automobiles. A huge amount of steel is used for the automobiles. Steel has many attractive features such as its inexpensive material, high strength and manageability, but it is too heavy. Therefore, the use of aluminum alloy which has a high specific strength leads to reduction in the weight of automobiles. Aluminum alloy, however, is expensive and has a low tensile strength compared with steel, but used in the right place leads to efficient weight reduction [1,2].

Generally, it is difficult to combine steel and aluminum alloy because of their differences in physical properties [1,4]. MAZDA, a Japanese automobile company, has developed a friction stir spot welding (FSSW) which is a new method to combine steel and aluminum alloy, but there are various problems such as low joint strength, long joint time, and a necessity for a new equipment to use FSSW. Therefore, it has been used only on the rear door and hood [5,6].

On the other hand, resistance spot welding (RSW) has been used in the fields of automotive manufacturing [3,7]. The possibility of combining steel and aluminum alloy has a great advantage to cost and productivity. The combination of steel and aluminum alloy with RSW, however, has a low joint strength and reliability because of its brittle intermetallic compound (IMC) layer formation [1-3].

In this paper, to improve the welded joint strength and reliability between stainless steel and aluminum alloy with RSW, the relation between the heat source and the electrode force were investigated.

EXPERIMENTAL PROCECURE

The stainless steel plate (SUS304) and the aluminum alloy plate (A6061-T6) of 2 mm thickness were prepared for RSW. The dimensions were decided by JIS Z 3136. The specimens were prepared by spot welding machine which utilizes the direct current inverter (SL-AI65-610, DAIHEN). The type of top electrode was CF type with a tip diameter of 6 mm tip diameter and the type of the bottom electrode was F type with a diameter of 25 mm. The electrode forces were from 1.9 kN to 9.3 kN. The welding currents were fixed at 18.1 kA. The impressed current time was 20 cycles and the holding time was 10 cycles (1 cycle is 1/60 s). The specimens for the tensile shear test were three pieces in each condition except in the case of electrode force of 1.9 kN. The tensile shear strength was measured by the universal testing machine (RH-30, Shimadzu Corporation). In order to analyze the relation between the heat source and the electrode force, the cross-section of the specimens were observed at each electrode force by optical microscope, scanning electron microscope (SEM) and electron probe microanalyzer (EPMA). Moreover, in order to analyze the heat affected zone (HAZ) of stainless steel, it was etched by a solution consisting of hydrochloric acid, nitric acid and acetic acid. The cross-section of the specimen after etching was observed by an optical microscope.

RESULTS AND DISCUSSIONS

The optical micrograph of the cross-section with each electrode force of 1.9 kN, 3.8 kN and 5.6 kN at the welding current of 18.1 kA were shown in Figure 1 (a), (b) and (c). From Figure 1 (a), the expansion direction was from the aluminum alloy side to the stainless steel side at area (A). Moreover, large voids existed near the interface of the aluminum alloy side. From Figure 1 (b), the expansion direction was from the aluminum alloy side to the stainless steel side at area (B) and from the stainless steel side to the aluminum alloy side atarea (C). Moreover, the voids existed in the middle interface of the aluminum alloy side. From Figure 1 (c), the expansion direction was from the stainless steel side to the aluminum alloy side at area (D). Moreover, no voids existed in the aluminum alloy side.The enlarged SEM photographs of the white box near each of the areas (A), (B), (C) and (D)in Figure 1 were shown in Figure 2. The bright gray area was for stainless steel, the black area was for aluminum alloy, and the dark gray parts were for IMCs. To identify the composition of the IMCs, line analysis of EPMA was conducted. From the EPMA result of direction 1 as shown in Figure 2 (a), Fe and Al contained around 20 % and 50 % in the dark gray parts similar to the pattern of aluminum alloy side, respectively. Fe_2Al_5 made by the welding between steel and aluminum alloy was generated [2, 7, 8]. EPMA result of direction 2 in Figure 2 (a) showed that the IMC layer which was Fe_2Al_5 was generated in the interface. Similarly, EPMA results of direction 4, 5 and 6 showed that the IMC layer was generated in the interface. From the EPMA result of direction 3 as shown in Figure 2 (b), Fe_2Al_5 appeared in the needle-like IMCs of the aluminum alloy side. The large IMCs did not appear in the aluminum alloy side as shown in Figure 2 (c). There were no dark gray parts as shown in Figure 2 (d). Which means that the IMCs did not appear in the aluminum alloy side.

The optical micrograph of the cross-section after etching were shown in Figure 1 (c), (d) and (e). From Figure 1 (c), the heat source existed in the interface at the electrode force of 1.9 kN because HAZ of stainless steel was thin, and the heat generated inside the stainless steel was small. From Figure 1 (e), the heat source existed inside the stainless steel at the electrode force of 5.6 kN because HAZ of stainless steel was thick, and the heat generated inside of stainless steel was

large. From Figure 1 (d), the electrode force of 3.8 kN was in a transient state. Therefore, the heat source was moved from the interface to inside of the stainless steel because the resistance of stainless steel surpassed the contact resistance of the interface by increasing the electrode force.

The relation between the tensile shear strength and the electrode force at the welding current of 18.1 kA was shown in Figure 3. The tensile shear strength at the electrode force of 1.9kN was very low compared with other electrode forces, because the bonding area was decreased by many voids and cracks were generated by the IMCs in the aluminum alloy side. The thickness of the IMC layer at the interface was around 1.5-2.5 µm from the enlarged SEM photograph in Figure 2 (a). Generally, it is known that when the thickness of the IMC layer at the interface exceeds 1.5 µm, the delamination strength decreases because of the brittleness [8]. The tensile shear strength at the electrode force of 3.8 kN showed quite variable results from around 5,000 N to around 9,000 N. Because the bonding area was decreased by the voids, cracks were generated by the needle-like IMCs in the middle aluminum alloy side, and the thickness of the IMC layer at the interface was around 1.5-2.5 µm from the enlarged SEM photograph in Figure 2 (b). The tensile shear strength at the electrode force of 3.8 kN, however, was higher than that of 1.9 kN due mainly to the small voids. The maximum mean value of the tensile shear strength was at the electrode force of 5.6 kN due to no voids and IMCs and the thin IMC layer occurred at the interface around 1.0-1.5 µm from the enlarged SEM photograph in Figure 2 (d). The tensile shear strength was decreased with the increase of the electrode force higher than 5.6 kN, because sufficient heat was not supplied to the welding area by increasing the electrode force.

CONCLUSIONS

In this paper, to clarify the relation between the heat source and the electrode force, a cross-section transformation with a variable electrode force with a fixed welding current was investigated. Based on optical micrograph after etching, HAZ area inside the stainless steel was increased by increasing the electrode force. Moreover, voids near the interface disappeared, which means that the heat source moved from the interface to the inside of the stainless steel. The tensile shear strength was high and its variability was low at the welding current of 18.1 kA and the electrode force of 5.6 kN because no voids and IMCs existed in the aluminum alloy side. In addition, the IMC layer was thin and the required heat amount was obtained.

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APPENDICES

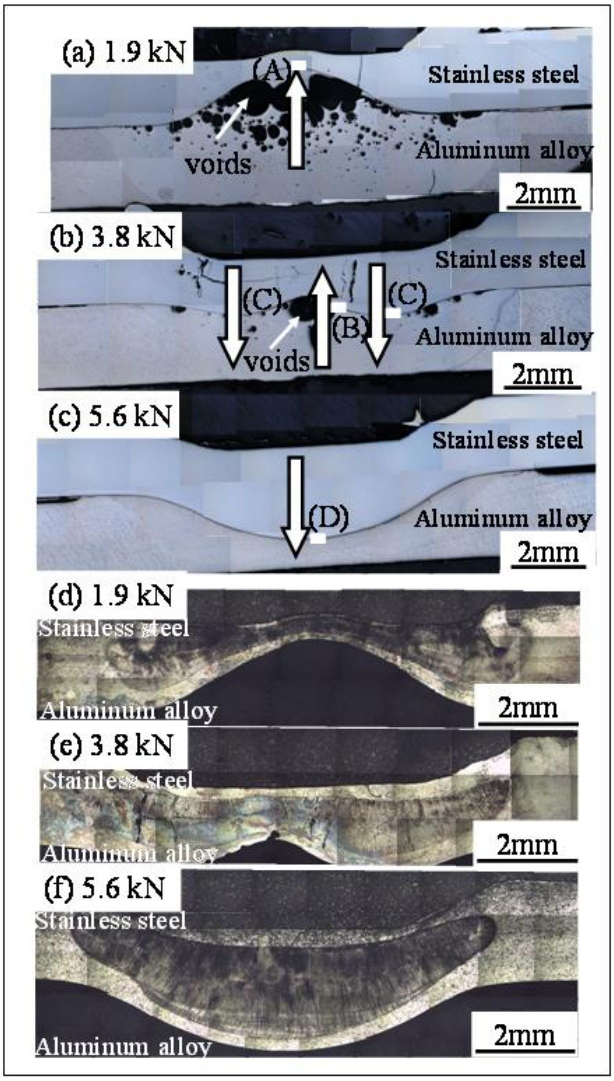

Figure 1: Optical Micrograph at Each Electrode force at the Welding Current of 18.1 kA
(a) 1.9 kN before Etching (b) 3.8 kN before Etching (c)5.6 kN before Etching
(d) 1.9 kN after Etching (e) 3.8 kN after Etching (f)5.6 kN after Etching

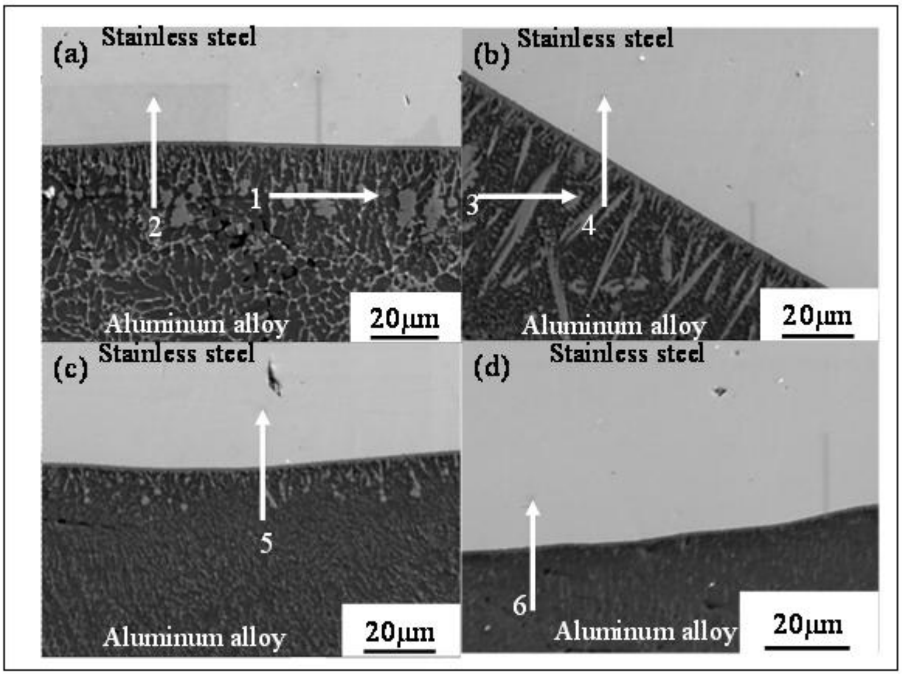

Figure 2 : Sem Photograph Magnified White Box of Figure1 (a)Area (A), (b) Area (B), (c) Area(C), (d) Area(D)

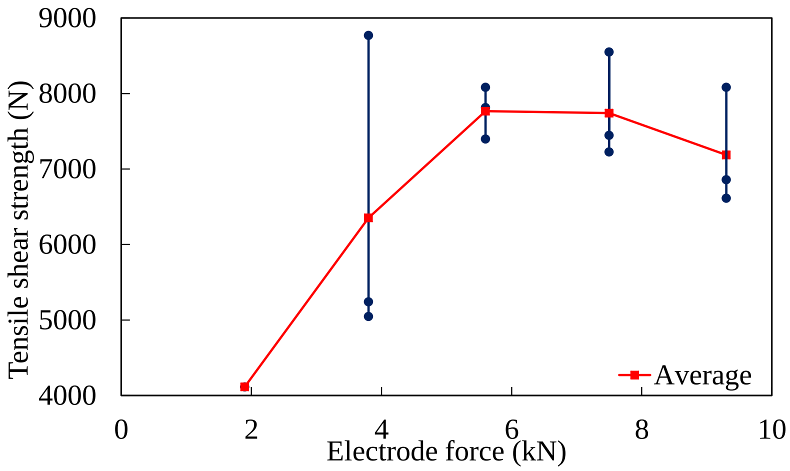

Figure 3 : Relation between Tensile Shear Strength and Electrode Force